

ALUMINUM AND ALUMINUM OXIDE IN ZERO GRAVITY

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ABSTRACT

An experiment is described to test the feasibility of using absence of gravity to mix immiscible materials. The mixing of aluminum oxide into molten aluminum has been chosen, as representative of the dispersing of immiscible solids into liquids. The equipment planned consists of a small self-contained furnace burning a Thermit mixture, which can handle some 100 grs. of metal. A gas operated stirrer will provide the mixing. One of two results is expected: 1. Mixing is successful. 2. Freezing produces separation. In either case, industrial exploitation is to be expected.

Since the beginning of time, men have tried to do things that are impossible. An idealist would call this the eternal striving of mankind toward a brighter future, a more down to earth person would see into it only man's basic inability to comprehend the laws of nature, but the fact remains that, given an insoluble problem, there is always some stubborn fool that will spend his lifetime on it and occasionally solve it in some fashion! One of these insoluble problems is mixing insoluble substances, that is, substances that are immiscible even in the liquid state. Probably the problem first arose when the ancient Greeks tried to make a salad dressing by mixing oil and vinegar, but through the ages the problem has remained unsolved: one still has to shake the bottle vigorously immediately before use.

Metallurgists have also encountered the problem: there are many metals that show interesting properties, when combined, but that are practically immiscible in the liquid state. An obvious example is lead, which imparts good machinability to most metals, but mixes only in limited amounts in them. When it comes to mixing nonmetallic compounds into metals the situation is even worse: the solubility of oxides, nitrides, etc., into metals often is measured in ppm. With vigorous stirring mixing can be accomplished, but it is not lasting. Within minutes or even seconds there is separation due to differences in specific gravity. Yet many products composed of mixtures of metals and compounds have outstanding (and unmatched) properties: dispersion strengthened metals, graphite-containing bearings, carbide cutting tools are some products of this type.

Some means have been found around the obstacle. Thus, we have powder metallurgy which avoids the liquid phase and relies upon mechanically mixed powders, and ultrasonic vibration to disperse solids in the liquids and keep them dispersed during freezing. Both methods are fairly successful for small size, but when large pieces have to be made, the equipment and power needs become impossible: one Kw of power can ultrasonically mix few grams of steel, but the equipment and power requirements to shake a 50-ton ladle of steel would dwarf a rocket to Mars.

This is the reason for the experiments planned. In absence of gravity there is no reason for two immiscible substances not to remain dispersed into each other once they have been thoroughly mixed. Most of us have seen pictures taken within spaceships showing droplets of liquid hanging in air. Why should not the same be true if the air is replaced by another liquid? If the two (or more) dispersed liquids are frozen, a solid should result with a free dispersion of one material into the other. This, of course, assumes that when the liquids freeze there is no pronounced segregation. Since most metals under normal conditions freeze dendritically, there is good reason to expect the dispersion to survive the freezing.

If for some unforeseen reason separation is achieved during the relatively rapid freezing that is planned, some very interesting possibilities appear. Separation of solids from liquids is a problem in the metallurgical industry, but much more so in the chemical industry. If filtration can be achieved just by freezing the liquid, decantation basins, filter presses and all similar equipment could be eliminated. It would be the equivalent of a zone refining operation in which the freezing front moves at the rate of feet per minute instead of the present inches per hour or per day! One outstanding feature of these two possibilities is that no matter how the experiment turns out, not only can we claim that it has been highly successful, but we can take pride in the fact that it worked exactly according to predictions!

The experiment planned involves the mixing of an insoluble solid into a liquid. The substances chosen are molten aluminum as liquid and Al_2O_3 as insoluble solid.

There are many reasons for this choice. First of all, Al_2O_3 is not wetted by aluminum even in vacuum so that we have a truly immiscible mixture. Aluminum is one of the few materials that has a relatively low melting point and very high boiling point so that when melted in the vacuum of space it does not evaporate into it: the oxide also has a very low vapor pressure and very high melting point so that even if the temperature control is far from accurate, there is no danger of melting it. No extra reaction can take place: the Al_2O_3 is very stable, whereas the suboxides Al_2O and AlO are unstable, as shown in Table 1 in which heats of formation are listed.

Table 1. Heats of Formation of Oxides

		<u>Reference</u>
Al_2O_3	400 kcal/gr. mole	(1)
Al_2O	250 kcal/gr. mole	(2)
AlO	97 kcal/gr. mole	(3)
	138 kcal/gr. mole	(2)
Fe_2O_3	196 kcal/gr. mole	(1)

- (1) L. S. Darken, R. W. Gurry, Physical Chemistry of Metals, McGraw Hill, 1953.
- (2) L. Brewer, A. W. Searcy, J. Am. Chem. Soc., 1951, 73, 5308.
- (3) E. Zintl and Coll., Z. Anorg. Allg. Chem., 1940, 245, 8.

Aluminum can be melted in graphite crucibles without contamination, and Al_2O_3 does not react to any appreciable extent with graphite at temperatures below 900°C . Thus no reactions with crucible material are to be expected and the crucible will not volatilize. Both aluminum and aluminum oxide have low density, thus reducing the weight of the experiment. Last, but not least, Revere is in the aluminum business and I have worked with it most of my life.

Fig. 1 shows a section through the planned set-up. As can be seen, there is a crucible with cover containing the metal to be melted and an area around it in which the fuel will be burned. As fuel a Thermit mixture will be used, to be ignited by a resistance. An insulating brick shell will surround the fuel zone to reverberate as much of the heat as possible to the crucible. Some preliminary calculations based on heats of reaction and fusion indicate that an amount of fuel of the same weight as the metal to be melted will be more than sufficient. This, however, is a very rough calculation with a figure for the heat transfer efficiency of 20%, which was picked out of thin air.

Before the actual experiment goes in space some trials will be run in vacuum and from the actual temperature reached in the metal, fuel quantity will be adjusted so that the metal inside the crucible melts for the few minutes required to stir the oxide into the melt before it freezes.

Above the crucible and its covers is the stirrer to rotate the stirring rod when the metal is molten. A gas stirrer has been chosen for several reasons: It is much lighter than an electric motor, it operates out of any compressed gas and is a standard item off the shelf. The most important reason for the choice, however, is that perfect timing is not needed. The gas can be turned on when ignition is started and even if it is on when the metal is frozen there will be no damage. If the stirring rod is not free, the stirrer does not rotate, but does not burn out or break the rod as would be the case for an electric motor. Actually it is planned to stop the stirring before freezing starts, either by turning off the gas or by supplying only the amount of gas sufficient for few minutes stirring. However, since the timing that applies on earth may not be valid in space, some extra safety is valuable.

One spot which may be critical and on which suggestions are welcome is the hole where the stirring rod enters the crucible. The amount of metal in the crucible will be such that the crucible is completely full with melt and oxide so as to reduce the formation of metal shot. Under gravity conditions the metal can be trusted to stay into the crucible, but in zero gravity it will be necessary to have a close fit between the rod and the graphite cover to insure against leakage. We are now building the whole assembly and plan to test it upside down in the hope

that the melt will not flow around the graphite stirrer, freeze against the steel shell and gum up the works. Around the crucible and the insulations there is a stainless steel shell with clamped on cover and everything will be inside a closed container of stainless steel so that even if something goes wrong and molten metal escapes from the crucible, it does not float out into the module and burn something.

As can be seen the experiment is relatively simple and does not need elaborate equipment. However, a great wealth of information can be expected from it. As mentioned before, if the mixing is successful a wide range of possibilities is open: many materials that today are used only in small articles because they are not available in large quantities may become commonplace. For example, the mixtures of aluminum and aluminum oxide have outstanding high temperature properties, but since they have to be fabricated by mixing aluminum powder and extruding it, they are available only as small rods or plates. If a 10-ton ingot of the mixture could be cast in space and then rolled on earth, a good part of the titanium sheet in supersonic planes could be replaced by aluminum with a decided saving in weight.

Fiber reinforced metals are another type of product which has outstanding possibilities and for which zero gravity may make an enormous difference. On earth, production of three dimensional structures is almost impossible, but in zero gravity it is no problem to build a three dimensional lattice of reinforcing fibers and then pour the bonding metal around and let it freeze. This experiment will also give information on the feasibility of this process. If it is found that little or no displacement of the immiscible solid takes place during freezing of the liquid, the making of fiber reinforced parts with tri-dimensional reinforcement becomes a relatively simple process. There are many more examples that can be mentioned. Moreover, if the process becomes commercial, many more applications will be found, that at present we cannot even imagine.

In addition to the main goal of establishing whether immiscible materials can be dispersed into each other in zero gravity or whether zero gravity can be used for separation, other information can be expected from this experiment. Solidification of metals on earth is always affected by convection currents that mix metal. What pattern of freezing and segregation can be expected in the absence of convection currents? Will segregation be more pronounced, will the mode of freezing be drastically altered, will the grain size be much different? I understand that other people have experiments on these questions; it will be interesting to compare results and see how many different interpretations can be given to the experimental data.

After this experiment is completed the next step depends a great deal on what the results are. If mixing is successful, then the obvious next steps are other immiscible materials and a larger size one to yield a casting that can be worked to sheet or rod and fabricated into experimental products. The large experiment should make a 5-10 lb. casting. The smaller experiments should be of the same size as the present one and planned to test one or more of the following products: fiber reinforced materials, graphite or lead-containing metal, hard particles dispersed into ductile metal, metal bonded fiberglass. Probably other combinations may become interesting. If instead of mixing, separation is achieved, the limits of the process should be explored. Several small experiments with different materials and conditions should be tried. This would require at least four or five separate experiments, all small scale.

In all these experiments the main limitation would be space available and weight. The other limitation: heat, is basically one of weight: given enough fuel it is no problem to melt not only the metal for the experiment, but the orbital workshop itself. Some tricky engineering may also be needed to design the equipment for the experiments, but I am sure that this is not an unsurmountable problem.

Altogether, I am looking forward to the day when this experiment will come back from space and I am very hopeful that this and other research will be successful, so that the program of space can continue at full speed. I feel that the work done here is among the most important for mankind, not because of the improved products that may come from this research program, but because only in space we will find a frontier.

I definitely think that when we can open space to colonization most of the present unrest and conflict will subside and that many people will be able to find in other planets the satisfaction and happiness that they cannot find in their present environment. In my opinion space exploration is more important to world peace than all the disarmament conferences and I hope that my modest contribution to the program can be of help.

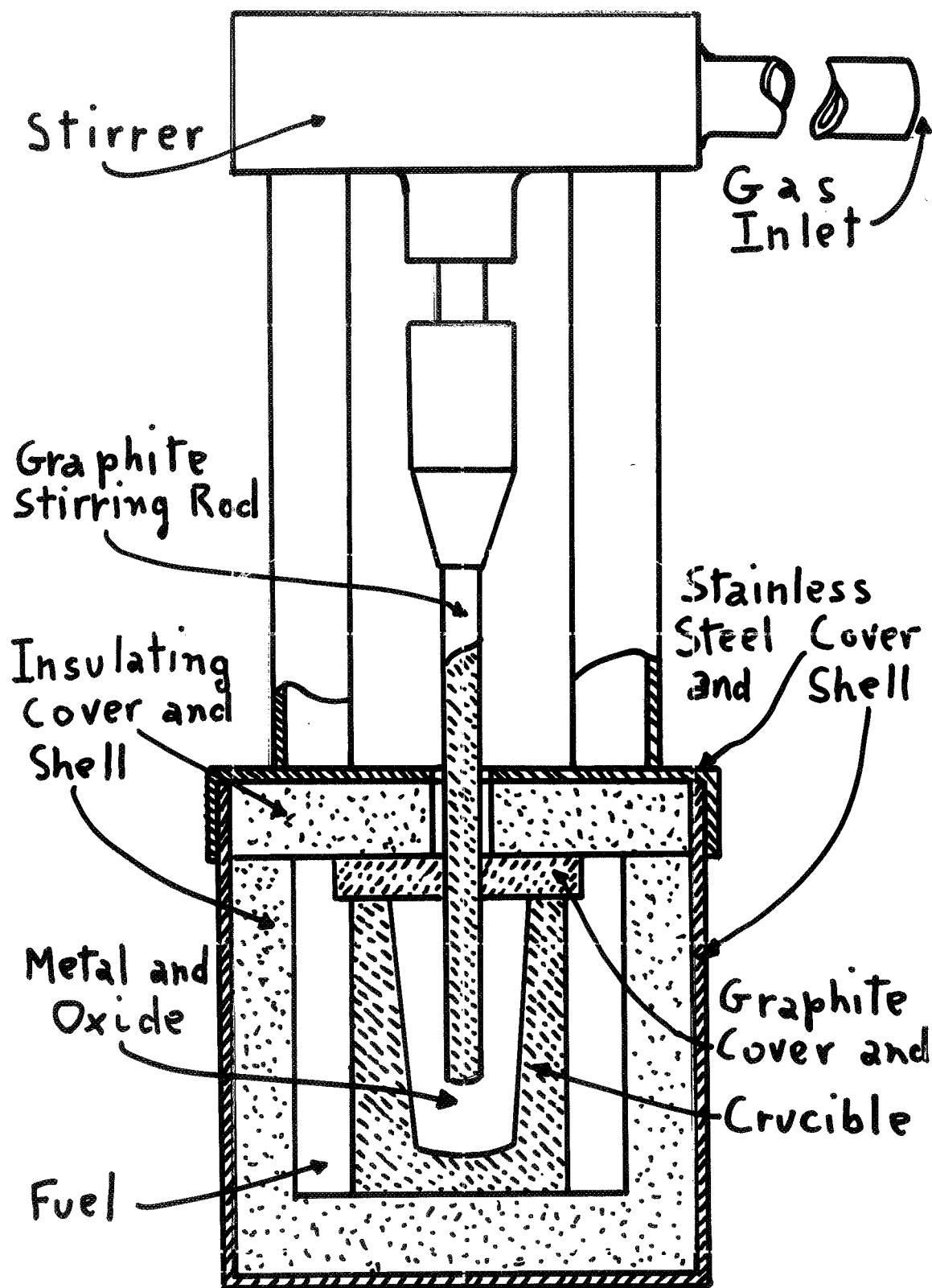


Figure 1